DOI: 10.1007/s11676-007-0043-7

Influence of Ammoniacal Copper Quaternary treatments on mechanical properties of blue-stained Lodgepole Pine wood

JIANG Jing-hui, REN Hai-qing, LU Jian-xiong, LUO Xiu-qin, WU Yu-zhang

Research Institute of Wood Industry, Chinese Academy of Forestry; Key Laboratory of Wood Science and Technology of State Forestry Administration, Beijing 100091 China

Abstract Three concentrations (2.8%, 2.0%, 1.2%) of Ammoniacal Copper Quaternary (ACQ) was selected to treat Lodgepole pine wood for evaluating ACQ treatment on mechanical properties of blue-stained wood. The bending modules of elasticity (MOE), modules of rupture (MOR), toughness and shearing strength parallel to grain on tangential surface, are tested according to the criteria GB1927~1943-91. Non-treated sample were also tested according to the same procedure. The results showed that the three groups specimen impregnated by different concentrations of ACQ solution met the AWPA standard 2003 of America (UC4A 6.4g/cm^3). There were significant difference of toughness between treated wood and non-treated wood (p=0.01), but there were no statistically significant differences among three concentrations in terms of toughness, and toughness of treated wood was approximately 20% lower than non-treated. MOR, MOE as well as shearing strength parallel to grain were found to be not significantly different between treated wood and non-treated one, and there were no statistically significant difference among three concentrations of ACQ too. Toughness, MOR, MOE and shearing strength parallel to grain increased with decrease of concentration of ACQ, but they were hardly affected by ACQ preservatives.

Keywords: Lodgepole pine wood; Blue-treated wood; Non-treated wood; Toughness; Modules of rupture; Modules of elasticity; Shearing strength parallel to grain

Introduction

The major defining characteristics of lumber cut from trees that have been infected with the mountain pine (*Pinus montana* Mill.) beetle are the extension of blue-stained fungi in the sapwood (Byrne 2003). Previous studies showed that bending properties (MOE and Toughness) between blue-stained clear wood and non-stained one are comparable, in contrast, mean bending strength of non-stained wood are lower than blue-stained wood (Lu *et al.* 2005). On the other hand, the non-stained part of the specimen was rarely impregnated only the surface, in contrast, the blue-stained part was thoroughly impregnated. In order to extend the application of blue-stained Lodgepole pine (*Pinus contorta* Dougl. ex Loud) wood, preservative treatment test of the blue-stained wood with Ammoniacal Copper Quaternary (ACQ) of three different concentrations were conducted. To evaluate the influence of ACQ treatments on blue-stained wood mechanical properties, is to determine if blue-stained wood treated by three concentration of ACQ differs from blue-stained wood without treatment in respects of the following four mechanical properties: toughness, bending modulus of elasticity (MOE), modulus of rupture (MOR), and shearing strength parallel to grain on tangential surface.

Foudation project: Chinese Academy of Forestry cooperated with Canada Innovation Investment.

Received: 2007-06-7; Accepted: 2007-07-10

Electronic supplementary material is available in the online version of this article at http://dxdoi.org/10.1007/s11676-007-0043-7

Biography: Jiang Jinghui, male, Assistant Pro. Master, Major: Wood science and technology. Address: Research Institute of Wood Industry, Chinese Academy of Forestry; Beijing China, 100091. Tel：010-62889437 Email: jiangjh@forestry.ac.cn

Responsible editor: Chai Ruihai

Material and methods

Material

The blue-stained Lodgepole pine samples were collected from British Columbia, Canada. Toughness tests were carried out according to GB1940-91(1992). During the test, approximately 164 blue-stained clear specimens (20mm×20mm×300mm) with about 100% of blue-stained are used. Bending modulus of elasticity (MOE) and modulus of rupture (MOR) tests were carried out according to GB1936.1-91 and GB1936.2-91. During the test, approximately 120 blue-stained clear specimens, 20mm× 20mm ×300mm, with about 100% of blue-stained are used. The shear strength parallel to grain test was conducted according to GB1937-91, and during the test, approximately 144 blue-stained clear specimens (40mm×20mm×35mm) with about 60% of blue-stained are used, but a part of the sample sheared must be blue-stained.

ACQ solution are used conforming to ASTM 5654-95 (2000) and AWPA Standard 2003, ACQ must meet UC4A level, and retention of ACQ should equal to or surpass 6.4kg·m^{-3}, and based on the previous results, so concentrations of ACQ we chosen are 1.2%, 2.0% and 2.8% respectively.

Methods

Impregnating and drying

All the specimens were divided into four groups after air-seasoning. One group was not impregnated by the ACQ solution, and the other three groups were impregnated by ACQ solu-

tion with concentrations of 1.2%, 2.0%, 2.8% separately. In order to increase retention and depth of penetration, vacuum pressure treatment method was used. ACQ solution, as a sort of wood preservative solution, was impregnated into the specimen, draw a vacuum of 0.09 MPa and hold it for 30 min, then release the vacuum and apply a pressure of 0.8 MPa for 2 h. After that, the pressure was released for 5 min. Finally, each specimen was weighed again. As shown in Table 1, when the retention of three concentrations of ACQ exceed UC4A level of 6.4 kg·m^{-3}, the more the concentration of ACQ was required, the higher the retention of ACQ was. Other three groups were air-dried for two weeks, and the moisture content of treated specimen should be about 12% after oven dried at temperature of 60ºC, then, the specimens were conditioned over two weeks in a conditioning chamber set at a temperature of 20ºC and a relatively humidity of 65%.

Table1 Retention of Ammoniacal Copper Quaternary (ACQ)

Concentration of ACQ (%)	MOR and MOE		Toughness		Shearing strength	
	Retention (kg/m^3)	Coefficient of Variance (%)	Retention (kg·m^{-3})	Coefficient of Variance (%)	Retention (kg·m^{-3})	Coefficient of Variance (%)
1.2	7.8	9.19	7.9	6.37	6.9	11.98
2.0	13.5	5.58	13.3	5.94	11.7	12.55
2.8	19.0	4.40	18.3	8.03	16.4	12.04

Mechanical properties

Mechanical properties tests are in accordance with national standards of People's Republic of China testing methods for physical and mechanical properties of wood, using Japanese NMB company 5 ton universal mechanical testing machine and Ji Nan universal mechanical testing machine, in terms of toughness, bending modulus of elasticity (MOE), modulus of rupture (MOR), and shearing strength parallel to grain on tangential surface, to compare impregnated with non-impregnated blue-stained wood.

Toughness tests, following GB1940-91, were performed on three impregnated groups and one non-impregnated group, in each group, there are 41 of clear specimens. The average moisture content of toughness test specimens in this study is approximately 10.88%.

Bending modulus of elasticity (MOE) and modulus of rupture (MOR) tests, following GB1936.1-91and GB1936.2-91, were performed on the four groups. There were 30 clear specimens in each group. The displacement rate of the crosshead was maintained at 2.5 mm·min^{-1}. This resulted in an average time to failure of about 1.5 min. Prior to calculating both MOE and MOR in the bending test, cross-section was measured. Although all specimens were conditioned to an equilibrium moisture content corresponding to a constant environment of a temperature of 20ºC and a relative humidity of 65%, blocks were cut from the samples and the moisture content was determined by the oven drying. The average moisture content was found to be 11.84% with a coefficient of variance of 9.76%.

Shearing strength parallel to grain on tangential surface tests, following GB1937-91, were performed on the four groups, in each group there were 36 clear specimens measuring 40mm×20mm×35mm. The displacement rate of the crosshead was remained constant. This leads to an average time to failure of about 1.5 min. Although all specimens were conditioned to an equilibrium moisture content corresponding to a constant environment of a temperature of 20ºC and a relative humidity of 65%, blocks were cut from the samples and the moisture content were determined by oven drying. The average moisture content was found to be 10.88% with a coefficient of covariance of 3.5%.

Results and discussions

Toughness

As shown in Table 2, the toughness of the non-treated blue-stained sample was higher than the treated ones, and the mean toughness of the non-treated sample is 29.4 kJ·m^{-2}. The three kinds of concentration of ACQ are 1.2%, 2.0% and 2.8% respectively, the mean toughness of the three treated groups are 25.2, 24.2 and 22.5 kJ·m^{-2} in sequence. The concentration of ACQ increased as the toughness decreased (see in Fig. 1).

As shown in Table 3, analysis of variance showed that there were very significant differences in toughness between treated and non-treated blue-stained specimen, however, there were no statistically significant differences among three concentration of ACQ (see in Table 4).

Table 2 Toughness test results ·

Concentration of ACQ (%)	Sample size	Toughness (kJ·m^{-2})			Coefficient of Variance (%)
		Max	Min	Mean	
Non-treated	41	43.7	13.6	29.4	27.3
1.2	41	48.6	13.1	25.2	33.7
2.0	41	37.3	14.3	24.2	27.0
2.8	41	47.0	11.7	22.5	29.9

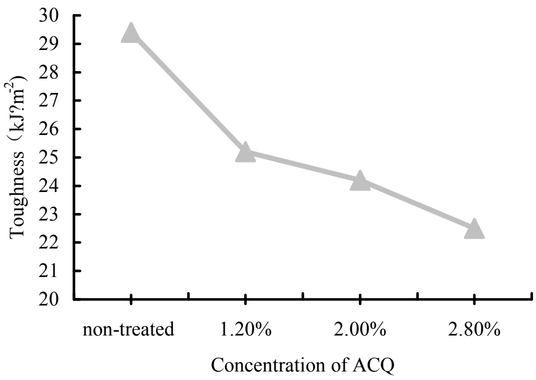

Fig. 1 the concentration of ACQ and Toughness relationship

Table 3 Variance analysis on toughness of blue-stained wood treated by the ACQ solution and non-treated

Source	SS	df	MS	F-value	P-value	Significance level
Brand	1119.32	3	373.1065	8.75572	2.06E-05	***
Error	6818.063	160	42.61289			
Total	7937.382	163				

Table 4 Variance analysis on toughness of blue-stained wood treated by three concentration of ACQ solution

Source	SS	df	MS	F-value	P-value	Significance level
Brand	164.8941	2	82.44707	1.95278	0.146362	*
Error	5066.444	120	42.22037			
Total	5231.338	122				

Note：***: 0.01 Significance level，**: 0.05 Significance level，*:Not Significant

Modulus of elasticity and modulus of rupture

As shown in Table 5, the mean MOE of specimens treated by ACQ of concentration of 1.2%, 2.0% and 2.8% respectively, are 13.6 MPa, 13.5 MPa and 12.9 MPa accordingly, and the mean MOE of non-treated was 13.0 MPa nearby the MOE of the ACQ of 2.8%. The concentration of ACQ increased as the MOE decreased (see in Fig. 2). As shown in Table 6, analysis of variance showed that there were no significant differences in MOE between treated and non-treated blue-stained specimens.

Table 5 MOE test results

Concentration of ACQ (%)	Sample size	MOE (MPa)			Coefficient of Variance (%)
		Max	Min	Mean	
Non-treated	30	18.1	8.8	13.0	16.3
1.2	30	16.8	10.6	13.6	12.5
2.0	30	20.5	10.5	13.5	17.2
2.8	30	19.4	9.4	12.9	18.9

Table 6 Variance analysis on MOE of blue-stained wood treated by the ACQ solution and non-treated

Source	SS	df	MS	F-value	P-value	Significant level
Brand	11.38483	3	3.794943	0.812702	0.489334	*
Error	541.6666	116	4.669539			
Total	553.0514	119				

Note：***: 0.01 Significance level，**: 0.05 Significance level，*:Not Significant

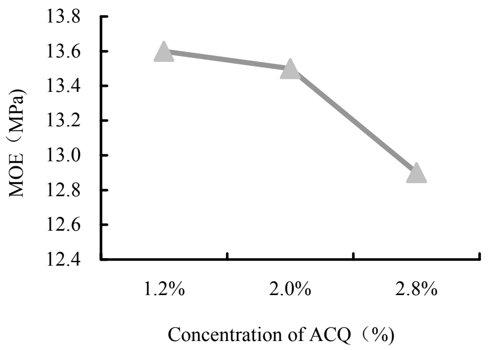

Fig. 2 The concentration of ACQ and MOE relationship

The result of MOR closely resembles that of MOE. As shown in table 7, the mean MOR of the non-treated blue-stained sample is 88.1 MPa, the mean MOR treated by ACQ of three concentration of 1.2%, 2.0% and 2.8% are 90.1MPa, 86.3 MPa and 82.9 MPa, respectively. The concentration of ACQ increased as the mean MOR decreased (Fig. 3). As shown in Table 8, the analysis of variance showed that there were not significant differences in MOR between treated and non-treated blue-stained specimens.

Table 7 MOR test results

Concentration of ACQ (%)	Sample size	Max (MPa)	Min (MPa)	Mean (MPa)	Coefficient of variance(%)
Non-treated	30	124.5	68.3	88.1	15.3
1.2	30	111.5	65.7	90.1	12.8
2.0	30	108.7	60.2	86.3	13.6
2.8	30	116.0	51.1	82.9	15.5

Table 8 Variance analysis on MOR of blue-stained wood treated by the ACQ solution and non-treated

Source	SS	df	MS	F-value	P-value	Significance level
Brand	857.2964	3	285.7655	1.843377	0.143165	*
Error	17982.65	116	155.0228			
Total	18839.94	119				

Note：***: 0.01 Significance level，**: 0.05 Significance level，*:Not Significant

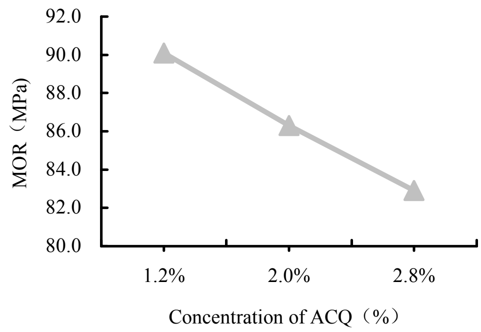

Fig. 3 The concentration of ACQ and MOR relationship

Previous studies showed that treatments of ACQ and CuAz of different concentrations had little influence to MOE and MOR, and there were no significant differences between treated and non-treated the wood of Fir (*Abies nephrolepis*) by Wang *et al.* (2004), which agree with our results.

Shearing strength parallel to grain on tangential surface

The result of shearing strength parallel to grain closely resembles that of bending tests. As shown in Table 9, the mean Shearing strength parallel to grain of the non-treated blue-stained sample is 8.8MPa, meanwhile, the mean Shearing strength parallel to grain treated by ACQ of three concentrations of 1.2%, 2.0% and 2.8% are 8.6MPa, 8.5MPa and 8.5MPa, respectively. The concentration of ACQ went up as the Shearing strength went down (see in figure 4). As shown in Table 10, the analysis of variance showed that there were not significant differences in Shearing

strength parallel to grain between treated and non-treated blue-stained specimens.

Table 9 Shearing strength parallel to grain on tangential surface

ACQ (%)	Sample size	Max (MPa)	Min (MPa)	Mean (MPa)	Coefficient of variance (%)
Non-treated	32	10.9	7.1	8.8	11.4
1.2	32	11.3	7.0	8.6	13.1
2.0	32	10.4	6.0	8.5	13.0
2.8	32	10.8	6.2	8.5	13.3

Table 10 Variance analysis on shearing strength parallel to grain on tangential surface of blue-stained wood treated by the ACQ solution and non-treated

Source	SS	df	MS	F value	P-value	Significance level
Brand	2.492877	3	0.830959	0.695321	0.556598	*
Error	148.1891	124	1.195073			
Total	150.6819	127				

Note：***: 0.01 Significance level，**: 0.05 Significance level，*:Not Significant

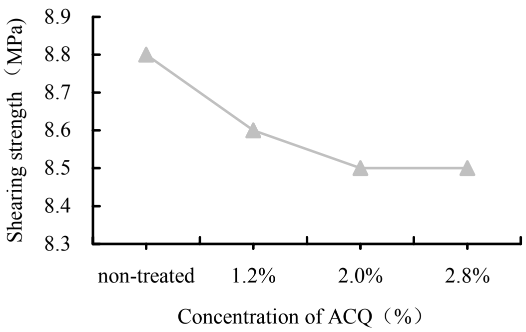

Fig. 4 Concentration of ACQ and shearing strength parallel to grain on tangential surface relationship

Conclusions

The whole specimen impregnated by ACQ solution with concentration of 2.8%, 2.0%, 1.2%, respectively, can meet the AWPA standard 2003 of America (UC4A 6.4kg/m^3).

There were significant difference of toughness between treated wood and non-treated wood (p=0.01), but there are not statistically significant in terms of ACQ of three concentration, the concentration of ACQ fell as the toughness rose.

MOR, MOE as well as shearing strength parallel to grain between treated blue-stained wood and non-treated one was found to be not significantly different, and there are not statistically significant different among ACQ of three concentration, the concentration of ACQ became lower as MOR, MOE and shearing strength parallel to grain got higher.

MOR, MOE as well as shearing strength parallel to grain were hardly affected by ACQ preservatives，but toughness by treated ACQ were approximately 20% lower than non-treated wood.

References

American Society for Testing and Materials. 2000, 4 (10) D5654-95，Standard specification for ammoniacal copper quat type B (ACQ-B),: 628–629.

American Wood Preservatives' Association (AWPA) Standard.2003, E7-01: Method of evaluating wood preservatives by field tests with stakes.

Byrne, A. 2003. Characterizing the properties of wood containing beetle-transmitted bluestain: background, material collection and summary of findings, Forintek Canada Corp. report to the Forest Innovation Investment Program. Vancouver. BC.

Lu Jianxiong, Fu Feng, Ren Haiqing. 2005. Characterizing the properties of bluestained Lodgepole pine wood of British Columbia, Canada. Chinese Academy of Forestry report to the Forest Innovation Investment Program. Beijing, China

National Standards of People's Republic of China. 1991.GB1927~1943-91. *Testing methods for physical and mechanical properties of wood*. Beijing: Standards Press of China,.

Wang Zhao-hui, Wu Yu-zhang, Fei Ben-hua, Jiang Ming-liang. 2004. Influence of ACQ and CuAz treatments on wood mechanical properties. *China Wood Industry*, **18**(3), 17~19, 22.